Search for the Lepton Flavor Violation Processes $J/\psi \to \mu\tau$ and $e\tau$

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Abstract

The lepton flavor violation processes $J/\psi \to \mu\tau$ and $e\tau$ are searched for using a sample of 5.8×10^7 J/ψ events collected with the BESII detector. Zero and one candidate events, consistent with the estimated background, are observed in $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ decays, respectively. Upper limits on the branching ratios are determined to be $Br(J/\psi \to \mu\tau) < 2.0 \times 10^{-6}$ and $Br(J/\psi \to e\tau) < 8.3 \times 10^{-6}$ at the 90% confidence level (C.L.).

PACS: 13.25.Gv, 14.40.Gx, 13.40.Hq

1 Introduction

In the Standard Model (SM), lepton flavor is conserved, but it is expected to be violated in many extensions of the SM, such as grand unified models [1], supersymmetric models [2], left-right symmetric models [3], and models where electroweak symmetry is broken dynamically [4]. Recent experimental results from Super-Kamiokande [5], SNO [6], and KamLAND [7] indicate strongly that neutrinos have masses and can mix with each other. Consequently, lepton flavor symmetry is a broken symmetry. There have been many studies both experimentally and theoretically on searching for lepton flavor violating (LFV) processes [8], mainly from μ, τ and Z decays [9]. Theoretical predictions of LFV in decays of charmonium and bottomonium systems are discussed in Refs. [10,11,12], and the search for the $J/\psi \to e\mu$ LFV process at BESII is presented in Ref. [13]. In this paper, we report on a search for LFV via the

decays $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ using $5.8 \times 10^7 J/\psi$ events collected with the BESII detector.

2 BES detector

The Beijing Spectrometer (BES) [14,15] is a conventional solenoidal magnetic detector at the Beijing Electron Positron Collider (BEPC). The upgraded version of the BES detector, BESII, includes a 12-layer vertex chamber (VC), surrounding the beam pipe and providing trigger information; a fourty-layer main drift chamber (MDC), located radially outside the VC and providing trajectory and energy loss (dE/dx) information for charged tracks over 85% of the total solid angle; and an array of 48 scintillation counters surrounding the MDC to measure the time-of-flight (TOF) of charged tracks with a resolution of $\sim$ 200 ps for hadrons. The momentum resolution of the MDC is $\sigma_p/p = 1.78\%\sqrt{1+p^2}$ (p in GeV/c), and the dE/dx resolution for hadron tracks is about 8%. Radially outside the TOF system is a 12 radiation length, lead-gas barrel shower counter (BSC). This measures the energies of electrons and photons with an energy resolution of $\sigma_E/E = 21\%/\sqrt{E}$ (E in GeV). Outside the solenoidal coil, which provides a 0.4 Tesla magnetic field over the tracking volume, is an iron flux return that is instrumented with three double layers of counters to identify muons of momentum greater than 0.5 GeV/c. It provides coordinate measurements with resolutions in the outermost layer of 10 cm and 12 cm in $r\phi$ and z. The solid angle coverage of the layers is 67%, 67%, and 63% of 4π, respectively.

In the analysis, a GEANT3 based Monte Carlo program (SIMBES) with detailed consideration of detector performance (such as dead electronic channels) is used. The consistency between data and Monte Carlo has been checked in many high purity physics channels, and the agreement is reasonable.

3 Event selection

We require candidate events for $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ to have two well reconstructed and oppositely charged tracks, each of which is well fitted to a helix originating from the interaction region of $|x|$ <0.015 m, $|y|$ <0.015 m, and $|z| < 0.15$ m and with a polar angle, θ, satisfying $|\cos\theta| < 0.8$. To reject cosmic rays, the time of flight difference of the two charged tracks should be less than 4 ns.

Isolated photons are defined as those photons having an energy deposit in the BSC greater than 50 MeV, an angle with any charged track greater than 15°,

and an angle between the direction defined by the first layer hit in the BSC and the developing direction of the cluster in the xy-plane less than 18°. There must be no isolated photon in the selected event.

Information from the BSC, TOF, and MDC (dE/dx) is used to select electrons. Fig. 1(a) shows the ratio of the energy deposited by the electron in the BSC to its momentum (E/P) for Monte Carlo simulated events, and Fig. 1(b) shows the energy deposited by the muon in the BSC for Monte-Carlo simulated events. To be an electron, the charged track should have no hits in the muon counter, and the E/P ratio should be larger than 0.7. To further distinguish the electron from hadrons, it is required that $\wp^{e}_{dE/dx} > \wp^{\pi}_{dE/dx}$, $\wp^{e}_{dE/dx} > \wp^{K}_{dE/dx}$ and $\wp^{e}_{TOF} > \wp^{p}_{TOF}$, where $\wp^{i}_{dE/dx}$ and $\wp^{i}_{TOF}$ are the particle identification confidence levels for the dE/dx and TOF measurements and i denotes e, π, K or p.

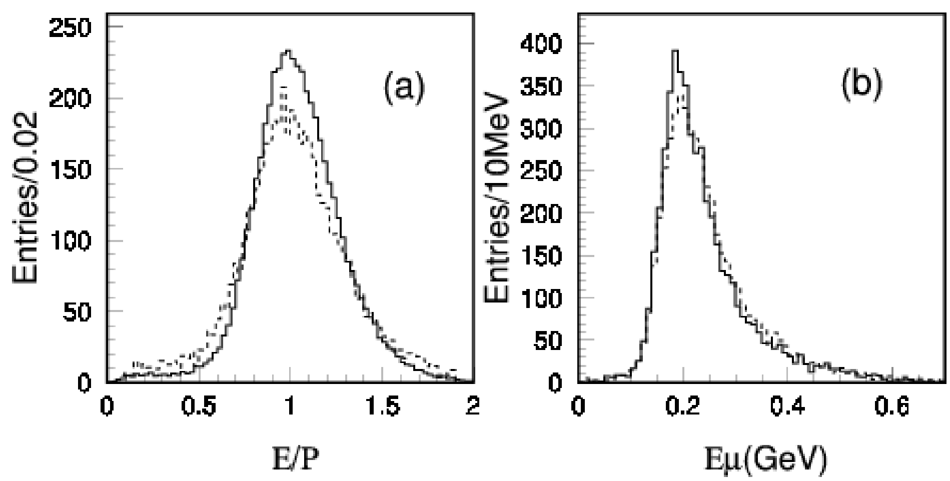

Fig. 1. (a.) Distribution of E/P for electrons (MC simulation). (b.) Distribution of energy deposited by muons in the BSC (MC simulation). The solid histogram represents $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_{\mu}\nu_{\tau}$ channel, and the dashed one is for $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_{e}\nu_{\tau}$ channel.

To select muon tracks, the differences, $\delta_i (i = r\phi, z)$, between the closest muon hit and the projected MDC track in each layer are used. A good hit in the μ counter requires $|\delta_i| < 2\sigma_i$ for $i = r\phi$ and z. The total number of good μ hits in the μ counter, μ^{good}_{hit}, can range from 0 to 3. A track is considered as a muon if the deposited energy in the BSC, shown in Fig. 1(b), is less than 0.3 GeV and μ^{good}_{hit} is equal to 3.

For the decay of $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_{\mu}\nu_{\tau}$, the momentum of the electron is monochromatic, while that of the muon is broad, as shown in Fig. 2. The main background for this channel comes from $J/\psi \to (\gamma)\mu^{+}\mu^{-}$ and $e^{+}e^{-} \to (\gamma)\mu^{+}\mu^{-}$, which is shown as the dashed histogram in Fig. 2. This background can be rejected by requiring that the momentum of the electron P_e be in the region from 1.00 to 1.08 GeV/c and the momentum of the muon be less than

1.4 GeV/c. Similar requirements $P_e < 1.4$ GeV/c and $1.00 < P_\mu < 1.08$ GeV/c are applied to $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ candidates to suppress the background from $J/\psi \to (\gamma)e^+e^-$ and $e^+e^- \to (\gamma)e^+e^-$. Applying these requirements, no candidates for $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and one candidate for $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ survive.

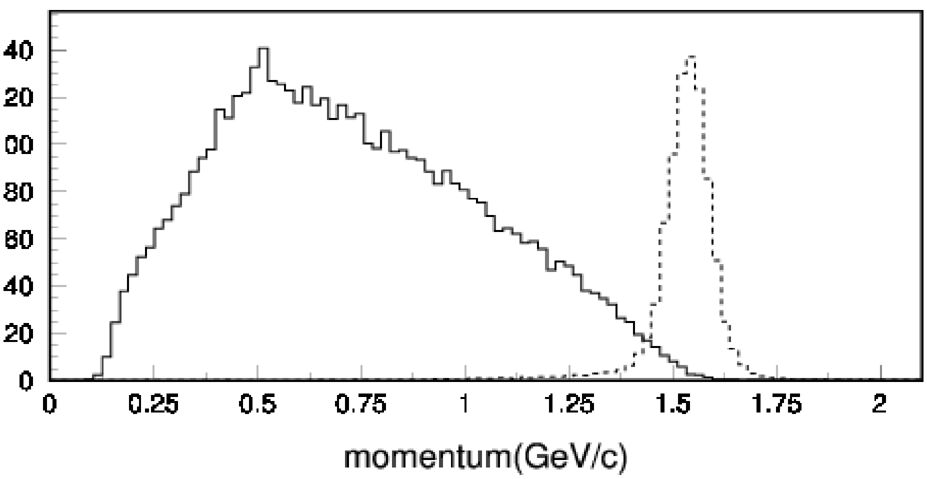

Fig. 2. Monte-Carlo distributions of muon momentum. The solid histogram represents $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ channel, and the dashed one is for the $J/\psi \to (\gamma)\mu^+\mu^-$ channel.

4 Efficiencies and backgrounds

In this analysis, the μ particle identification efficiency $\epsilon_{\mu PID}$ in the μ counter is determined using real μ tracks. All other efficiencies, including the geometric acceptance, momentum requirement efficiency, electron particle identification efficiency, etc., are combined into one term, ϵ_{MC}, which is determined by Monte-Carlo simulation. The overall efficiency is calculated as ϵ_{total}=$\epsilon_{\mu PID} \times \epsilon_{MC}$.

The μ track sample selected from 5.8×10^7 $J/\psi \to (\gamma)\mu^+\mu^-$ decays, as described in Ref. [13], is used to determine the μ particle identification efficiencies in both channels. The μ particle identification efficiency is a function of the transverse momentum, P_{xy}, of the muon. Therefore, $\epsilon_{\mu PID}$ is determined from $\sum\limits_i \epsilon_i\varpi_i$, where ϵ_i is the μ particle identification efficiency in the ith P_{xy} bin determined from the μ track sample, and ϖ_i is the weight corresponding to the number of events in the bin determined from the signal MC. Table 1 lists the ϵ_i and ϖ_i in the different P_{xy} regions, and Table 2 lists the selection efficiencies.

The remaining background in both the $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ processes are studied through Monte Carlo simulation. Almost all two-prong decay modes are generated with 5 to 10 times the number of

Table 1
The ϵ_i and ϖ_i values in different P_{xy} regions in the $J/\psi \to \mu\tau$ and eτ channels.

		$J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$	$J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$
P_{xy} (GeV/c)	ϵ_i (%)	ϖ_i	ϖ_i
$0.5 < P_{xy} < 0.6$	0.0	0.0	13.7
$0.6 < P_{xy} < 0.7$	0.0	3.1	12.3
$0.7 < P_{xy} < 0.8$	8.1	11.3	10.9
$0.8 < P_{xy} < 0.9$	40.6	17.8	9.7
$0.9 < P_{xy} < 1.0$	52.2	33.9	7.9
$1.0 < P_{xy} < 1.1$	53.4	33.9	6.3
$1.1 < P_{xy} < 1.2$	56.2	0.0	4.5
$1.2 < P_{xy} < 1.3$	57.7	0.0	2.8
$1.3 < P_{xy} < 1.4$	53.6	0.0	1.0

Table 2
Efficiency summary

	J/$\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ (%)	J/$\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ (%)
$\epsilon_{\mu PID}$	43.9	17.0
ϵ_{MC}	26.2	28.1
ϵ_{total}	11.5	4.8

events expected from $5.8 \times 10^7 J/\psi$ events. For $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$, the estimated background is about 0.4 events from $J/\psi \to \bar{K}^*(892)^- K^+ (+c.c.)$. For the decay $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$, no simulated events survive.

5 Systematic errors

The systematic errors in the branching ratio measurements come from the uncertainty of the MDC tracking efficiency for charged tracks, the error from the number of J/ψ events, the differences in the efficiencies between data and Monte-Carlo simulation for some selection criteria, such as the electron and muon identification criteria, as well as the uncertainty in τ decay branching ratio. The systematic errors from each source are listed in Table 3; the dominant error is from muon identification. Adding all the systematic errors in quadrature, the total systematic errors are 16.9% and 15.4% for $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ respectively.

Table 3
Summary of systematic errors

Source	$J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$(%)	$J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$(%)
e_{PID}	3.5	3.3
μ_{PID}	15.4	13.7
$Br(\tau$ decay)	0.3	0.4
MDC tracking	4.0	4.0
Number of J/ψ events [16]	4.7	4.7
Sum	16.9	15.4

6 Results and discussion

No $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ candidate and one $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$ candidate are observed from a sample of 5.8×10^7 J/ψ events, where the estimated background events in the two chanels are of 0 and 0.4 events, respectively. The background events are ignored for the conservative estimation. Upper limits on the branching ratios of $J/\psi \to \mu\tau$ and $J/\psi \to e\tau$ are calculated with:

$$Br(J/\psi \to X) < \frac{\lambda(N_{Signal}, N_{BG})}{N_{J/\psi} \times Br(X \to Y) \times \epsilon_{J/\psi \to X \to Y}},$$

where X and Y stand for the intermediate and final states, λ is the upper limit on the number of observed events at the 90% C.L., N_{Signal} and N_{BG} are the numbers of observed signal and background events respectively, $N_{J/\psi}$ represents the total number of J/ψ events, and ϵ is the detection efficiency. The values of $\lambda(N_{Signal}$ and $N_{BG})$ can be calculated using the method described in Refs. [17] and [18].

With the numbers summarized in Table 4, the upper limits on the branching ratios, after incorporating the systematic errors, are

$$Br(J/\psi \to \mu\tau) < 2.0 \times 10^{-6},$$

$$Br(J/\psi \to e\tau) < 8.3 \times 10^{-6}$$

at the 90% C.L.

Previously BES reported an upper limit on $Br(J/\psi \to e\mu)$ to be 1.1×10^{-6} at the 90 % C.L. [13].

In summary, the LFV processes $J/\psi \to \mu\tau$ and $e\tau$ are searched for using a sample of 5.8×10^7 J/ψ events. No candidate for $J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$ and one candidate for $J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$, consistent with the estimated

Table 4
Numbers and efficiencies used in the calculation of the upper limits.

	$J/\psi \to \mu\tau, \tau \to e\bar{\nu}_e\nu_\tau$	$J/\psi \to e\tau, \tau \to \mu\bar{\nu}_\mu\nu_\tau$
N_{bg}	0	0
$\epsilon(\%)$	11.5	4.8
$N_{J/\psi}$	5.8×10^7	5.8×10^7
N_{Signal}	0	1
$\lambda(N_{Signal}, N_{bg})$	2.4	4.0
Br(τ decay) (%)	17.84	17.37
Upper limit of Br.	2.0×10^{-6}	8.3×10^{-6}

background, are observed. The upper limits on the branching ratios at the 90% C.L. are determined to be $Br(J/\psi \to \mu\tau) < 2.0 \times 10^{-6}$ and $Br(J/\psi \to e\tau) < 8.3 \times 10^{-6}$.

7 Acknowledgments

The BES collaboration thanks the staff of BEPC and the computing center of IHEP for their hard efforts. We also thank Profs. Xinmin Zhang and Jianxiong Wang for helpful discussions. This work is supported in part by the National Natural Science Foundation of China under contracts Nos. 19991480,10225524, 10225525, the Chinese Academy of Sciences under contract No. KJ 95T-03, the 100 Talents Program of CAS under Contract Nos. U-11, U-24, U-25, and the Knowledge Innovation Project of CAS under Contract Nos. U-602, U-34 (IHEP); and by the National Natural Science Foundation of China under Contract No.10175060(USTC), and No.10225522(Tsinghua University). and by the Department of Energy under Contract No. DE-FG03-94ER40833 (U Hawaii).

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